A

Seminar report

On

PEROVSKITE SOLAR CELLS

Submitted in partial fulfillment of the requirement for the award of degree of ECE

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Acknowledgement

I would like to thank respected Mr…….. and Mr. ……..for giving me such a wonderful opportunity to expand my knowledge for my own branch and giving me guidelines to present a seminar report. It helped me a lot to realize of what we study for.

Secondly, I would like to thank my parents who patiently helped me as i went through my work and helped to modify and eliminate some of the irrelevant or un-necessary stuffs.

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Next, I would thank Microsoft for developing such a wonderful tool like MS Word. It helped my work a lot to remain error-free.

Last but clearly not the least, I would thank The Almighty for giving me strength to complete my report on time.

Preface

I have made this report file on the topic **PEROVSKITE SOLAR CELLS**; I have tried my best to elucidate all the relevant detail to the topic to be included in the report. While in the beginning I have tried to give a general view about this topic.

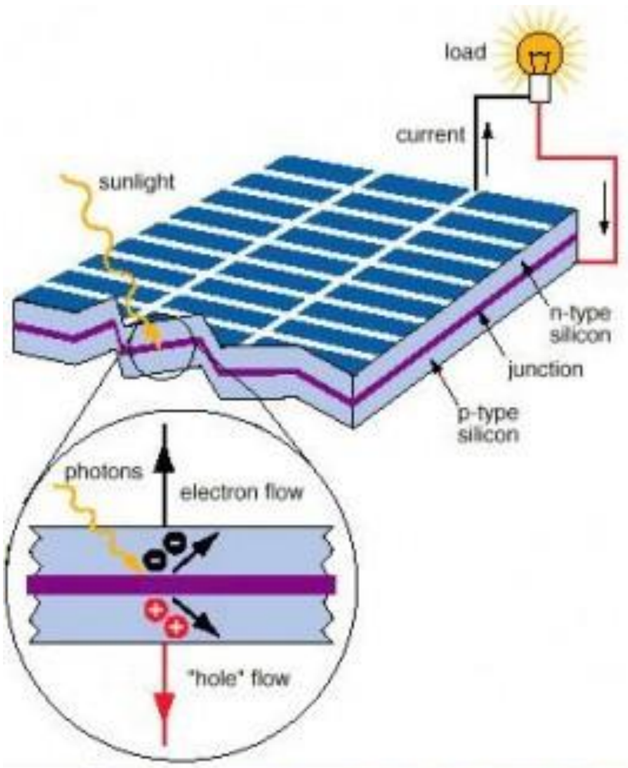
My efforts and wholehearted co-corporation of each and everyone has ended on a successful note. I express my sincere gratitude to …………..who assisting me throughout the preparation of this topic. I thank him for providing me the reinforcement, confidence and most importantly the track for the topic whenever I needed it.

CONTENT

1. What is a solar cell?

A solar cell (photovoltaic cell or photoelectric cell) is a solid state electrical device that converts the energy of light directly into electricity by the photovoltaic effect. The energy of light is transmitted by photons-small packets or quantums of light. Electrical energy is stored in electromagnetic fields, which in turn can make a current of electrons flow.

Assemblies of solar cells are used to make solar modules which are used to capture energy from sunlight. When multiple modules are assembled together (such as prior to installation on a pole-mounted tracker system), the resulting integrated group of modules all oriented in one plane is referred as a solar panel. The electrical energy generated from solar modules, is an example of solar energy. Photovoltaics is the field of technology and research related to the practical application of photovoltaic cells in producing electricity from light, though it is often used specifically to refer to the generation of electricity from sunlight. Cells are described as photovoltaic cells when the light source is not necessarily sunlight. These are used for detecting light or other electromagnetic radiation near the visible range, for example infrared detectors, or measurement of light intensity.



2. History and Development of Solar Cell Technology

The development of solar cell technology began with the 1839 research of French physicist Antoine-César Becquerel. Becquerel observed the photovoltaic effect while experimenting with a solid electrode in an electrolyte solution when he saw a voltage develop when light fell upon the electrode. The major events are discussed briefly below, and other milestones can be accessed by clicking on the image shown below.

- *Charles Fritts* - **First Solar Cell***:* The first genuine solar cell was built around 1883 by Charles Fritts, who used junctions formed by coating selenium (a semiconductor) with an extremely thin layer of gold. The device was only about 1 percent efficient.
- *Albert Einstein* - **Photoelectric Effect***:* Albert Einstein explained the photoelectric effect in 1905 for which he received the Nobel Prize in Physics in 1921.
- *Russell Ohl* - **Silicon Solar Cell***:* Early solar cells, however, had energy conversion efficiencies of under one percent. In 1941, the silicon solar cell was invented by Russell Ohl.
- *Gerald Pearson, Calvin Fuller and Daryl Chapin* - **Efficient Solar Cells***:* In 1954, three American researchers, Gerald Pearson, Calvin Fuller and Daryl Chapin, designed a silicon solar cell capable of a six percent energy conversion efficiency with direct sunlight. They

created the first solar panels. Bell Laboratories in New York announced the prototype manufacture of a new solar battery. Bell had funded the research. The first public service trial of the Bell Solar Battery began with a telephone carrier system (Americus, Georgia) on October 4 1955.

3. Generations of Solar Cells:

3.1 First Generation: Crystalline Silicon Solar Cell Technology

First generation solar cells are the larger, silicon-based photovoltaic cells. Silicon's ability to remain a semiconductor at higher temperatures has made it a highly attractive raw material for solar panels. Silicon's abundance, however, does not ease the challenges of harvesting and processing it into a usable material for microchips and silicon panels. Solar cells, use silicon wafers consisting of Silicon or Germanium that are doped with Phosphorus and Boron in a pn-junction. Silicon cells have a quite high efficiency, but very pure silicon is needed, and due to the energy-requiring process, the price is high compared to the power output. Crystalline Silicon Solar Cells dominate 80-90% of solar cell market due to their high efficiency, despite their high manufacturing costs

3.2 Second Generation: Thin Film Solar Cell Technology

Second generation solar cell, also known as thin-film solar cell (TFSC) or thin-film photovoltaic cell (TFPV), is made by depositing one or more thin layers (thin films) of photovoltaic material on a substrate. They are significantly cheaper to produce than first generation cells but have lower efficiencies. The great advantage of thin-film solar cells, along with low cost, is their flexibility and versatility to be used in varied environments. This has led to aesthetically pleasing solar innovations such as solar shingles, solar glass and solar panels that can be rolled out onto a roof or other surface. The most successful second generation materials have been cadmium telluride (CdTe), copper indium gallium selenide(CIGS), amorphous silicon and micro amorphous silicon. The thickness range of such a layer is wide and varies from a few nanometers to tens of micrometers. These materials are applied in a thin film to a supporting substrate such as glass or ceramics reducing material mass and therefore costs. It is predicted that second generation cells will dominate the residential solar market.

3.3 Third Genaration: Dye-Sensitized Solar Cell Technology

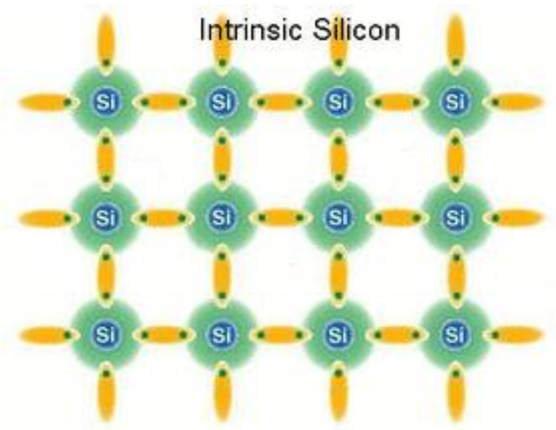
The electrochemical dye solar cell was invented in 1988 by Professor Graetzel of Lausanne Polytechnique, in Switzerland. The "Graetzel" dye cell uses dye molecules adsorbed in nanocrystalline oxide semiconductors, such as TiO_2, to collect sunlight. Dye cells employ relatively inexpensive materials such as glass, Titania powder, and carbon powder. Graetzel's cell is composed of a porous layer of titanium dioxide nanoparticles, covered with a molecular dye that absorbs sunlight, like the chlorophyll does in green leaves. Third generation solar cells are the cutting edge of solar technology. These solar cells can exceed the theoretical solar conversion efficiency limit for a single energy threshold material. Current research is targeting conversion efficiencies of 30-60% while retaining low cost materials and manufacturing techniques. Third generation contains a wide range of potential solar innovations including multijunction solar cells, polymer solar cells, nanocrystalline-nanowire cells, quantum dot solar cells anddye sensitized solar cells.

4. How do Solar Cells Work?

Solar cells, which largely are made from crystalline silicon work on the principle of Photoelectric Effect that this semiconductor exhibits. Silicon in its purest form- Intrinsic Silicon- is doped with a dopant impurity to yield Extrinsic Silicon of desired characteristic (p-type or n-type Silicon). Working of Solar cells can thus be based on crystalline structure of Intrinsic and Extrinsic Silicon. When p and n type silicon combine they result in formation of potential barrier. These and more are discussed below.

4.1 Pure Silicon (Intrinsic) Crystalline Structure

Silicon has some special chemical properties, especially in its crystalline form. An atom of silicon has 14 electrons, arranged in three different shells. The first two shells- which hold two and eight electrons respectively- are completely full. The outer shell, however, is only half full with just four electrons (Valence electrons). A silicon atom will always look for ways to fill up its last shell, and to do this, it will share electrons with four nearby atoms. It's like each atom holds hands with its neighbors, except that in this case, each atom has four hands joined to four neighbors. That's what forms the crystalline structure. The only problem is that pure crystalline silicon is a poor conductor of electricity because none of its electrons are free to move about, unlike the electrons in more optimum conductors like copper

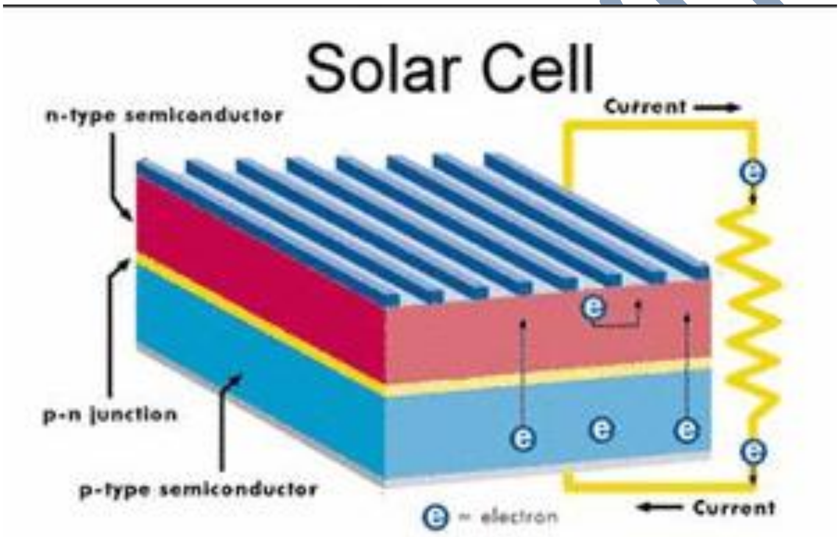


4.2 Impurity Added Silicon (Extrinsic): P-type and N-type Semiconductors

Extrinsic silicon in a solar cell has added impurity atoms purposefully mixed in with the silicon atoms, maybe one for every million silicon atoms. Phosphorous has five electrons in its outer shell. It bonds with its silicon neighbor atoms having valency of 4, but in a sense, the phosphorous has one electron that doesn't have anyone to bond with. It doesn't form part of a bond, but there is a positive proton in the phosphorous nucleus holding it in place. When energy is added to pure silicon, in the form of heat, it causes a few electrons to break free of their bonds and leave their atoms. A hole is left behind in each case. These electrons, called free carriers, then wander randomly around the crystalline lattice looking for another hole to fall into and carry an electrical current. In Phosphorous-doped Silicon, it takes a lot less energy to knock loose one of "extra" phosphorous electrons because they aren't tied up in a bond with any neighboring atoms. As a result, most of these electrons break free, and release a lot more free carriers than in pure silicon. The process of adding impurities on purpose is called doping, and when doped with phosphorous, the resulting silicon is called N-type ("n" for negative) because of the prevalence of free electrons. N-type doped silicon is a much better conductor than pure silicon.The other part of a typical solar cell is doped with the element boron, which has only three electrons in its outer shell instead of four, to become P-type silicon. Instead of having free electrons, P-type ("p" for positive) has free openings and carries the opposite (positive) charge

4.3 Formation of Potential Barrier and Photoelectric Effect

The electric field is formed when the N-type and P-type silicon come into contact. Suddenly, the free electrons on the N side combine the openings on the P side. Right at the junction, they combine and form something of a barrier, making it harder and harder for electrons on the N side to cross over to the P side (called POTENTIAL BARRIER). Eventually, equilibrium is reached, and an electric field separating the two sides is set up. This electric field acts as a diode, allowing (and even pushing) electrons to flow from the P side to the N side, but not the other way around. It's like a hill -- electrons can easily go down the hill (to the N side), but can't climb it (to the P side).

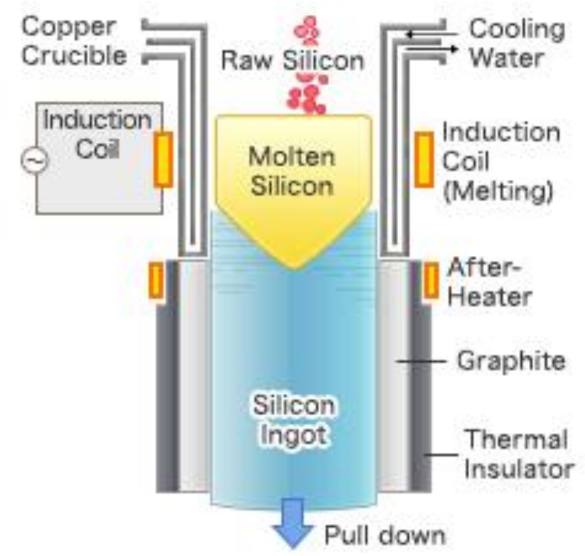


When light, in the form of photons, hits solar cell, its energy breaks apart electron-hole pairs(Photoelectric effect). Each photon with enough energy will normally free exactly one electron, resulting in a free hole as well. If this happens close enough to the electric field, or if free electron and free hole happen to wander into its range of influence, the field will send the electron to the N side and the hole to the P side. This causes further disruption of electrical neutrality, and if an external current path is provided, electrons will flow through the path to the P side to unite with holes that the electric field sent there, doing work for us along the way. The electron flow provides the current, and the cell's electric field causes a voltage.

Silicon is very shiny material, which can send photons bouncing away before energizing the electrons, so an antireflective coating is applied to reduce those losses. The final step is to install something that will protect the cell from the external elements- often a glass cover plate. PV modules are generally made by connecting several individual cells together to achieve useful levels of voltage and current, and putting them in a sturdy frame complete with positive and negative terminals.

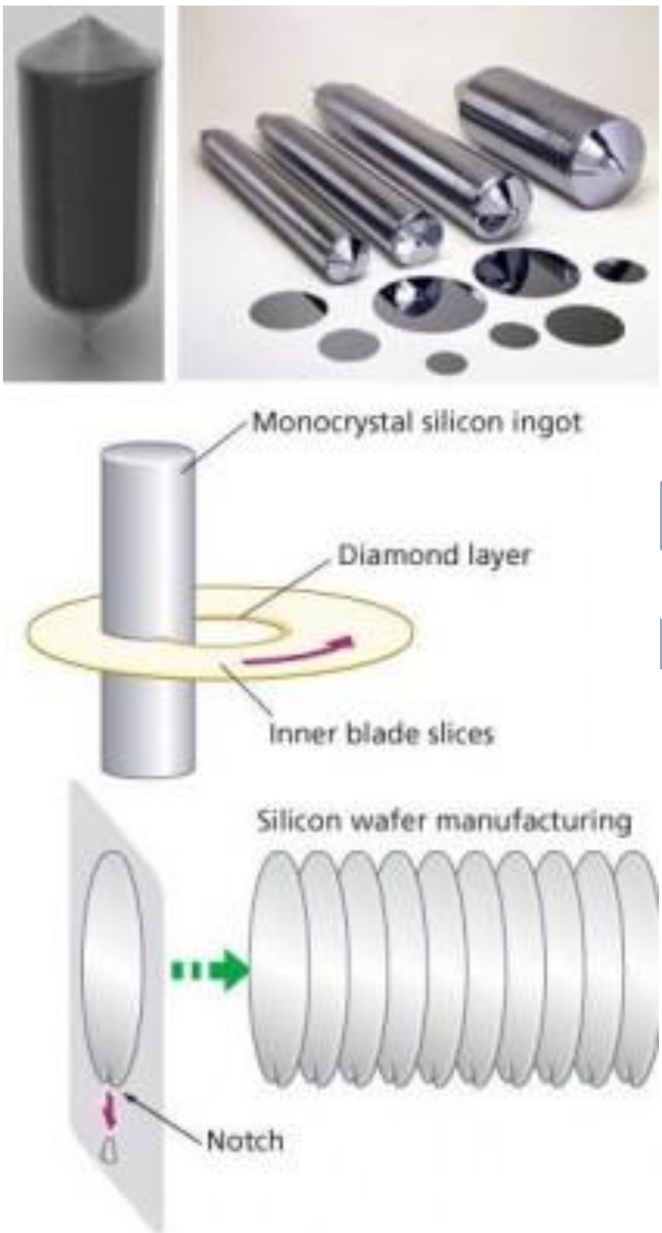
5. Manufacturing Technology and Process

5.1 STEP 1 - PURIFICATION OF SILICON:



The basic component of a solar cell is intrinsic silicon, which is not pure in its natural state. To make solar cells, the raw materials—silicon dioxide of either quartzite gravel or crushed quartz—are first placed into an electric arc furnace, where a carbon arc is applied to release the oxygen. A Graphite and Thermal insulator trap the heat and maintain the furnace at required temperature for gangue (impurity) to form a slag. The products are carbon dioxide and molten silicon. Silicon ingot is pulled down from the molten silicon using seed silicon crystallization and floating zone technique. Passing impure silicon in same direction several times that separates impurities- and impure end is later removed. This process yields silicon with one percent impurity, useful in many industries but not the solar cell industry. At this point, the silicon is still not pure enough to be used for solor cells and requires further purification. Pure silicon is derived from such silicon dioxides as quartzite gravel (the purest silica) or crushed quartz.

5.2 STEP 2- INGOT AND WAFER PREPARATION:

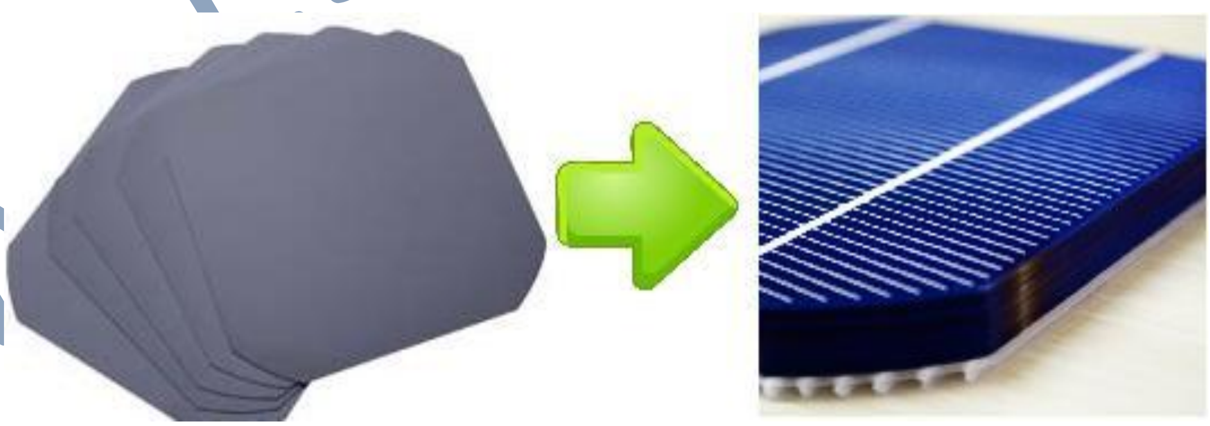


Solar cells are made from silicon boules, polycrystalline structures that have the atomic structure of a single crystal. The most commonly used process for creating the boule is called the Czochralski method. In this process, a seed crystal of silicon is dipped into melted polycrystalline silicon. As the seed crystal is withdrawn and rotated, a cylindrical ingot or "boule" of silicon is formed. The ingot withdrawn is unusually pure, because impurities tend to remain in the liquid. From the boule, silicon wafers are sliced one at a time using a circular saw whose inner diameter cuts into the rod, or many at once with a multiwire saw. (A diamond saw produces cuts that are as wide as the wafer—. 5 millimeter thick.) Only about one-half of the silicon is lost from the boule to the finished circular wafer—more if the wafer is then cut to be rectangular or hexagonal. Rectangular or hexagonal wafers are sometimes used in solar cells because they can be fitted together perfectly, thereby utilizing all available space on the front surface of the solar cell. The wafers are then polished to remove saw marks.

5.3 STEP 3 - DOPING:

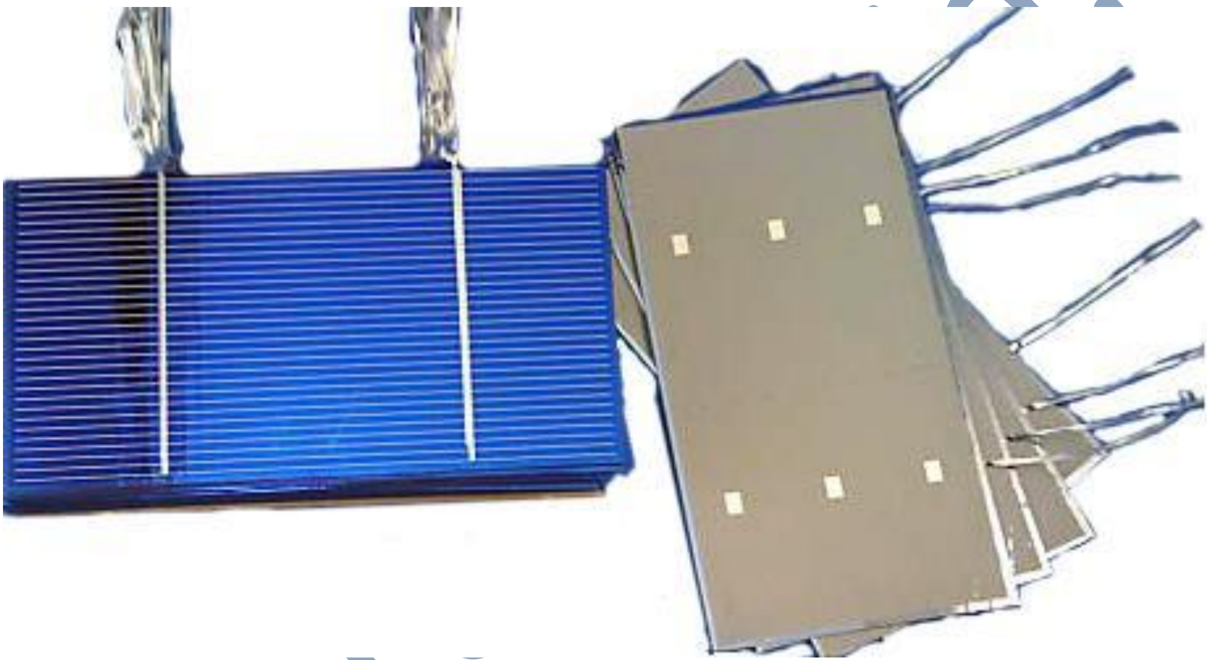
The traditional way of doping silicon wafers with boron and phosphorous is to introduce a small amount of boron during the Czochralski process. The wafers are then sealed back to back and placed in a furnace to be heated to slightly below the melting point of silicon (2,570 degrees Fahrenheit or 1,410 degrees Celsius) in the presence of phosphorous gas. The phosphorous atoms "burrow" into the silicon, which is more porous because it is close to becoming a liquid. The temperature and time given to the process is carefully controlled to ensure a uniform junction of proper depth. These diffusion processes are usually performed through the use of a batch tube furnace or an in-line continuous furnace.The basic furnace construction and process are very similar to the process steps used by packaging engineers.

5.4 STEP 4 - SCREEN PRINTING:



Electrical contacts are formed through squeezing a metal paste through mesh screens to create a metal grid. This metal paste (usually Ag or Al) needs to be dried so that subsequent layers can be screen-printed using the same method. As a last step, the wafer is heated in a continuous firing furnace at temperatures ranging from 780 to 900°C. These grid- pattern metal screens act as collector electrodes that carry electrons and complete the electrical continuity in the circuit.

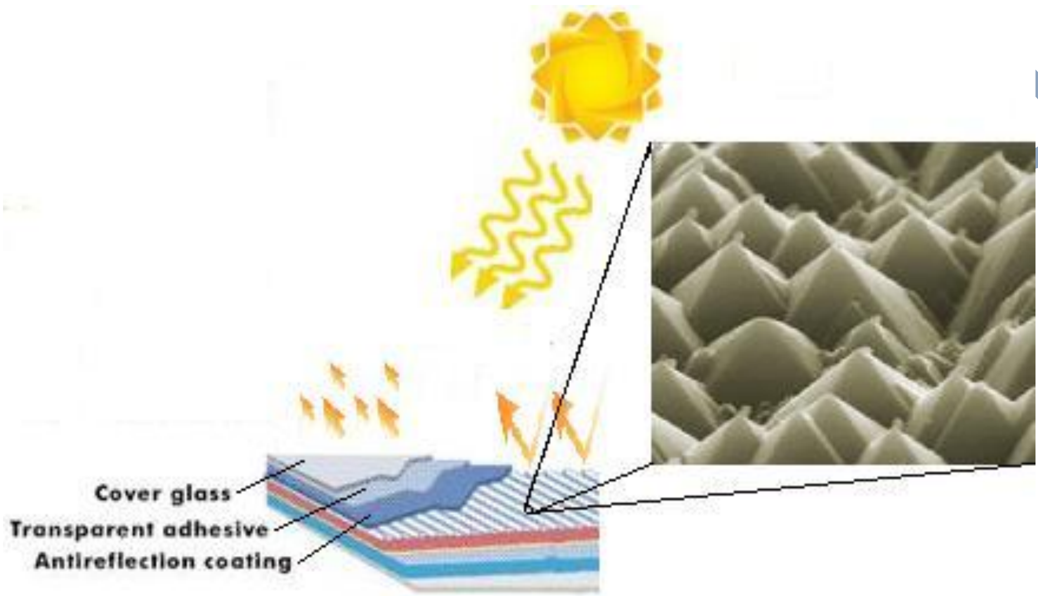
5.5 STEP 5 - STRINGING AND TABBING:



Electrical contacts connect each solar cell to another and to the receiver of produced current. The contacts must be very thin (at least in the front) so as not to block sunlight to the cell. Metals such as palladium/silver, nickel, or copper are vacuum-evaporated After the contacts are in place, thin strips ("fingers") are placed between cells. The most commonly used strips are tin-coated copper.

5.6 STEP 6 - ANTIREFLECTIVE COATING:

Because pure silicon is shiny, it can reflect up to 35 percent of the sunlight. To reduce the amount of sunlight lost, an anti-reflective coating is put on the silicon wafer- mostly titanium dioxide, silicon oxide and some others are used. The material used for coating is either heated until its molecules boil off and travel to the silicon and condense, or the material undergoes sputtering. In this process, a high voltage knocks molecules off the material and deposits them onto the silicon at the opposite electrode. Yet another method is to allow the silicon itself to react with oxygen- or nitrogen-containing gases to form silicon dioxide or silicon nitride. Commercial solar cell manufacturers use silicon nitride. Another method to make silicon absorb more light is to make its top surface grained, i.e. pyramid shaped nanostructures that yield 70% absorption that reaches the cell surface after passing through anti-reflective coating.



5.7 STEP 7 - MODULE MANUFACTURING

The finished solar cells are then encapsulated; that is, sealed into silicon rubber or ethylene vinyl acetate. Solar module assembly usually involves soldering cells together to produce a 36-cell string (or longer) and laminating it between toughened glass on the top and a polymeric backing sheet on the bottom. The encapsulated solar cells are then placed into an aluminum frame that has a mylar or tedlarbacksheet and a glass or plastic cover. Frames are usually applied to allow for mounting in the field, or the laminates may be separately integrated into a mounting system for a specific application such as integration into a building.

6. Application of Solar Cell:

Solar cells are often electrically connected and encapsulated as a **module**. Photovoltaic modules often have a sheet of glass on the front (sun up) side, allowing light to pass while protecting the semiconductor wafers from abrasion and impact due to wind-driven debris, rain,hail, etc. Solar cells are also usually connected in series in modules, creating an additive voltage. Connecting cells in parallel will yield a higher current; however, very significant problems exist with parallel connections. For example, shadow effects can shut down the weaker (less illuminated) parallel string (a number of series connected cells) causing substantial power loss and even damaging the weaker string because of the excessive reverse bias applied to the shadowed cells by their illuminated partners. Strings of series cells are usually handled independently and not connected in parallel, special paralleling circuits are the exceptions. Although modules can be interconnected to create an **array** with the desired peak DC voltage and loading current capacity, using independent MPPTs (maximum power point trackers) provides a better solution. In the absence of paralleling circuits, shunt diodes can be used to reduce the power loss due to shadowing in arrays with series/parallel connected cells.

6.1 Rural electrification:

The provision of electricity to rural areas derives important social and economic benefits to remote communities throughout the world. Power supply to remote houses or villages, electrification of the health care facilities, irrigation and water supply and treatment are just few examples of such applications.

The potential for PV powered rural applications is enormous. The UN estimates that two million villages within 20 of the equator have neither grid electricity nor easy access to fossil fuel. It is also estimated that 80% of all people worldwide do not have electricity, with a large number of these people living in climates ideally suited to PV applications. Even in Europe, several hundred thousand houses in permanent occupation (and yet more holiday homes) do not have access to grid electricity.

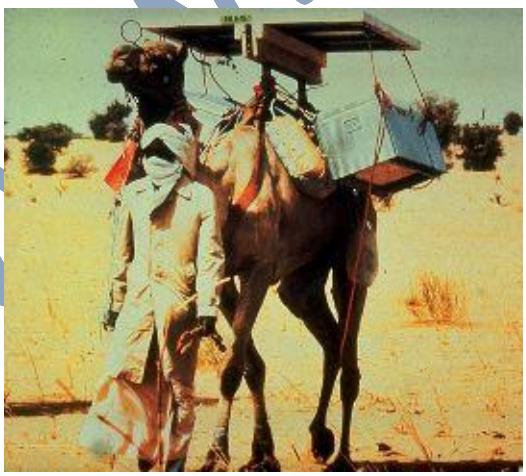
The economics of PV systems compares favourably with the usual alternative forms of rural electricity supply, grid extension and diesel generators. The extension and subsequent maintenance of transmission lines over long distances of often a difficult terrain is expensive, particularly if the loads are relatively small. Regular fuel supply to diesel generators, on the other hand, often present problems in rural areas, in addition to the maintenance of the generating equipment.

6.1.1 Water pumping:

More than 10,000 PV powered water pumps are known to be successfully operating throughout the world. Solar pumps are used principally for two applications: village water supply (including livestock watering), and irrigation. Since villages need a steady supply of water, provision has to be made for water storage for periods of low insolation. In contrast, crops have variable water requirements during the year which can often be met by supplying water directly to produce without the need for a storage tank.

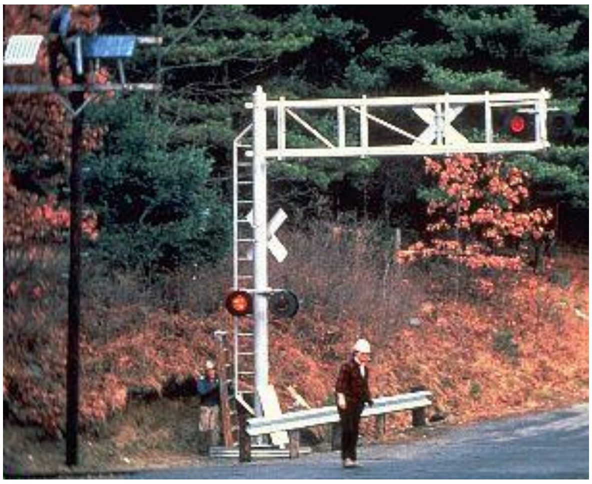
6.1.2 Health care:

Extensive vaccination programmes are in progress throughout the developing world in the fight against common diseases. To be effective, these programmes must provide immunisation services to rural areas. All vaccines have to be kept within a strict temperature range throughout transportation and storage. The provision of refrigeration for this aim is known as the vaccine cold chain.



6.1.3 Lighting:

In terms of the number of installations, lighting is presently the biggest application of photovoltaics, with tens of thousands of units installed world-wide. They are mainly used to provide lighting for domestic or community buildings, such as schools or health centres. PV is also being increasingly used for lighting streets and tunnels, and for security lighting.



6.2 Professional applications:

For some time, photovoltaic modules have proved to be a good source of power for high-reliability remote industrial use in inaccessible locations, or where the small amount of power required is more economically met from a stand-alone PV system than from mains electricity. Examples of these applications include:

6.2.1 Ocean navigation aids:

many lighthouses and most buoys are now powered by solar cells.

6.2.2 Telecommunication systems:

radio transceivers on mountain tops, or telephone boxes in the country can often be solar powered.

6.2.3 Remote monitoring and control:

scientific research stations, seismic recording, weather stations, etc. Use very little power which, in combination with a dependable battery, is provided reliably by a small PV module.

6.2.4 Cathodic protection

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this is a method for shielding metalwork from corrosion, for example, pipelines and other metal structures. A PV system is well suited to this application since a DC source of power is required in remote locations along the path of a pipeline.

6.3 Electric power generation in space:

Photovoltaic solar generators have been and will remain the best choice for providing electrical power to satellites in an orbit around the Earth. Indeed, the use of solar cells on the U.S. satellite Vanguard I in 1958 demonstrated beyond doubt the first practical application of photovoltaics. Since then, the satellite power requirements have evolved from few Watts to several kiloWatts, with arrays approaching 100 kW being planned for a future space station.

A space solar array must be extremely reliable in the adverse conditions of space environment. Since it is very expensive to lift every kilogram of weight into the orbit, the space array should also have a high power-to-weight ratio.

6.4 Grid-connected systems:

PV Power Stations:

A PV power station feeds the generated power instantaneously into the utility distribution network (the 'grid') by means of one or more inverters and transformers. The first PV power station was built at Hysperia in southern California in 1982 with nominal power specification 1 MW, using crystalline silicon modules mounted on a 2 axis tracking system.

PV power stations may be approaching economic viability in locations where they assist the local grid during periods of peak demand, and obviate the need to construct a new power station. This is known as peak shaving. It can also be cheaper to place small PV plants within the transmission system rather than to upgrade it ('embedded' generation).

PV in buildings:

The main advantages of these distributed systems over large PV plants are as follows:

- There is no costs in buying the land and preparing the site.
- The transmission losses are much lower because the load is on the same site as the supply.
- The value of the PV electricity is also higher because it is equal to the selling price of the grid electricity which has been replaced, rather that to the cost of generating it.

However, it should also be noted that the price paid by utility companies for electricity exported from a decentralised source is a fraction of the utility sale price. The optimum economic benefit is therefore derived by consuming all PV produced electricity, with direct reduction of the energy imported from the utility. Thus grid connected PV systems are ideal for loads which vary in proportion to the irradiation. Typical loads are air-conditioning, refrigeration and pumping. Other significant loads can be timed to operate when PV power is likely to be available. Examples include washing machines and clothes dryers which can operate on timing clocks.

7. Efficiency of Solar Cell:

Solar efficiency refers to the amount of ambient light that can be converted into usable electricity. There are two ways to evaluate photovoltaic solar efficiency: You can look at solar cell efficiency or at solar panel efficiency. Solar cellefficiency is the amount of light that the individual solar cell converts to electricity. Solar cells are placed next to one another on top of a backsheet and are covered by glass to make up a solar panel.

Solar panel efficiency refers to the amount of light that the entire module converts to electricity. The efficiency of a solar panel is lower than that of a solar cell due to the spacing between cells and because the glass covering reflects away some of the sunlight. Consequently, you want to pay attention to solar panel efficiency because that will indicate how much electricity your solar energy system will actually generate.

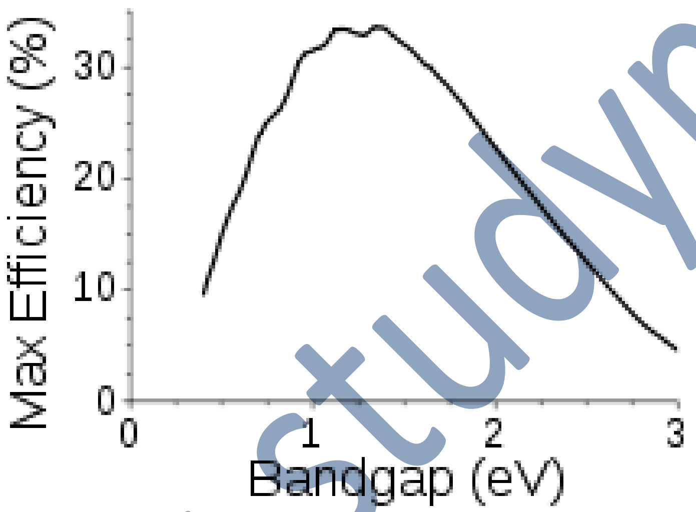
7.1 Why Is Solar Panel Efficiency Important?

High efficiency solar panels help you to maximize your overall return on investment for today and the future. These solar panels will:

- Generate more electricity with fewer panels
- Require less rooftop space
- Involve reduced installation time and fewer mounting materials
- Offer more long-term savings

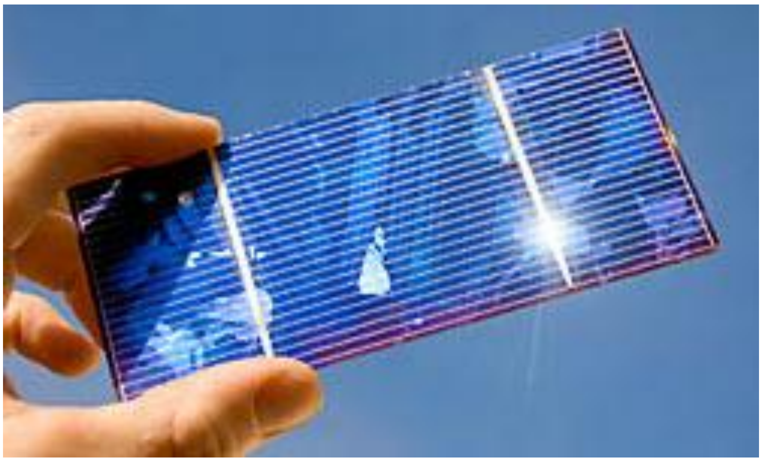
7.2 Efficiency Improvement:

Solar power is big. It's so big, in fact, that the Department of Energy recently promised up to $7 million in funding to support emerging solar technologies [source: DOE]. Harnessing the sun's energy is smart, but not as simple as it sounds.



It might be easier if we really could "harness" the sun, but that bright spot in the sky is elusive. Sometimes it hides behind clouds and, each night, it disappears altogether for hours at a time. The optimal time to mine the sun's energy is when it is highest in the sky, typically during the summer months when we also enjoy longer days with more average sunshine.

The researchers and engineers who design and build solar panels have to work with and around these factors all while devising new ways to not only collect but reserve free and renewable energy from the sun. For example, using mirrors, they've figured out a way to direct sunlight to solar panels even when the sun moves at an angle that normally would keep it from hitting those very panels.



On the next few pages, discover how innovative people are coming up with ways to use one of our most traditional energy sources more efficiently and effectively. You'll learn more about how solar panels can track the sun, how using different building materials increases efficiency and how solar concentrators channel light waves. Finally, you'll learn how "the sky's no limit" when it comes to collecting the sun's power for use here on Earth.

8. Cost of Solar Cell:

The cost of a solar cell is given per unit of peak electrical power. Solar-specific feed-in tariffs vary worldwide, and even state by state within various countries. Such feed-in tariffscan be highly effective in encouraging the development of solar power projects.

High-efficiency solar cells are of interest to decrease the cost of solar energy. Many of the costs of a solar power plant are proportional to the panel area or land area of the plant. A higher efficiency cell may reduce the required areas and so reduce the total plant cost, even if the cells themselves are more costly. Efficiencies of bare cells, to be useful in evaluating solar power plant economics, must be evaluated under realistic conditions. The basic parameters that need to be evaluated are the short circuit current, open circuit voltage.

The chart above illustrates the best laboratory efficiencies obtained for various materials and technologies, generally this is done on very small, i.e., one square cm, cells. Commercial efficiencies are significantly lower.

Grid parity, the point at which photovoltaic electricity is equal to or cheaper than grid power, can be reached using low cost solar cells. Proponents of solar hope to achieve grid parity first in areas with abundant sun and high costs for electricity such as in California and Japan.Some argue that grid parity has been reached in Hawaii and other islands that otherwise use diesel fuel to produce electricity. George W. Bush had set 2015 as the date for grid parity in the

USA. Speaking at a conference in 2007, General Electric's Chief Engineer predicted grid parity without subsidies in sunny parts of the United States by around 2015.

The price of solar panels fell steadily for 40 years, until 2004 when high subsidies in Germany drastically increased demand there and greatly increased the price of purified silicon (which is used in computer chips as well as solar panels). The recession of 2008 and the onset of Chinese manufacturing caused prices to resume their decline with vehemence. In the four years after January 2008 prices for solar modules in Germany dropped from €3 to €1 per peak watt. During that same times production capacity surged with an annual growth of more than 50%. China increased market share from 8% in 2008 to over 55% in the last quarter of 2010. Recently, in December 2012 the price of Chinese solar panels had dropped to $0.60/Wp (crystalline modules).

Swanson's law, an observation similar to Moore's Law that states that solar cell prices fall 20% for every doubling of industry capacity, has gained recent (as of 2012) media attention, having been featured in an article in the British weekly newspaper The Economist.

9. Materials used in Solar Cell:

Various materials display varying efficiencies and have varying costs. Materials for efficient solar cells must have characteristics matched to the spectrum of available light. Some cells are designed to efficiently convert wavelengths of solar light that reach the Earth surface. However, some solar cells are optimized for light absorption beyond Earth's atmosphere as well. Light absorbing materials can often be used in multiple physical configurations to take advantage of different light absorption and charge separation mechanisms.

Materials presently used for photovoltaic solar cells include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium selenide/sulfide.

Many currently available solar cells are made from bulk materials that are cut into wafers between 180 to 240 micrometers thick that are then processed like other semiconductors.

Other materials are made as thin-films layers, organic dyes, and organic polymers that are deposited on supporting substrates. A third group are made from nanocrystals and used as quantum dots (electron-confined nanoparticles). Silicon remains the only material that is well-researched in both bulk and thin-film forms.

9.1 Crystalline silicon:

By far, the most prevalent bulk material for solar cells is crystalline silicon (abbreviated as a group as c-Si), also known as "solar grade silicon". Bulk silicon is separated into multiple categories according to crystallinity and crystal size in the resulting ingot, ribbon, or wafer.

1. monocrystalline silicon (c-Si): often made using the Czochralski process. Single-crystal wafer cells tend to be expensive, and because they are cut from cylindrical ingots, do not completely cover a square solar cell module without a substantial waste of refined silicon. Hence most c-Si panels have uncovered gaps at the four corners of the cells.
2. polycrystalline silicon, or multicrystalline silicon, (poly-Si or mc-Si): made from cast square ingots — large blocks of molten silicon carefully cooled and solidified. Poly-Si cells are less expensive to produce than single crystal silicon cells, but are less efficient. United States Department of Energy data show that there were a higher number of polycrystalline sales than monocrystalline silicon sales.
3. ribbon silicon[27] is a type of polycrystalline silicon: it is formed by drawing flat thin films frommolten silicon and results in a polycrystalline structure. These cells have

lower efficiencies than poly-Si, but save on production costs due to a great reduction in silicon waste, as this approach does not require sawing from ingots.

4. mono-like-multi silicon: Developed in the 2000s and introduced commercially around 2009, mono-like-multi, or cast-mono, uses existing polycrystalline casting chambers with small "seeds" of mono material. The result is a bulk mono-like material with poly around the outsides. When sawn apart for processing, the inner sections are high-efficiency mono-like cells (but square instead of "clipped"), while the outer edges are sold off as conventional poly. The result is line that produces mono-like cells at poly-like prices.

Analysts have predicted that prices of polycrystalline silicon will drop as companies build additional polysilicon capacity quicker than the industry's projected demand. On the other hand, the cost of producing upgraded metallurgical-grade silicon, also known as UMG Si, can potentially be one-sixth that of making polysilicon.Manufacturers of wafer-based cells have responded to high silicon prices in 2004–2008 prices with rapid reductions in silicon consumption. According to JefPoortmans, director ofIMEC's organic and solar department, current cells use between eight and nine grams of silicon per watt of power generation, with wafer thicknesses in the neighborhood of 0.200 mm. At 2008 spring's IEEE Photovoltaic Specialists' Conference (PVS'08), John Wohlgemuth, staff scientist at BP Solar, reported that his company has qualified modules based on 0.180 mm thick wafers and is testing processes for 0.16 mm wafers cut with 0.1 mm wire. IMEC's road map, presented at the organization's recent annual research review meeting, envisions use of 0.08 mm wafers by 2015.

9.2 Thin films:

Thin-film technologies reduce the amount of material required in creating the active material of solar cell. Most thin film solar cells are sandwiched between two panes of glass to make a module. Since silicon solar panels only use one pane of glass, thin film panels are approximately twice as heavy as crystalline silicon panels. The majority of film panels have significantly lower conversion efficiencies, lagging silicon by two to three percentage points.[31] Thin-film solar technologies have enjoyed large investment due to the success of First Solar and the largely unfulfilled promise of lower cost and flexibility compared to wafer silicon cells, but they have not become mainstream solar products due to their lower efficiency and corresponding larger area consumption per watt production. Cadmium telluride (CdTe), copper indium gallium selenide (CIGS) and amorphous silicon (A-Si) are three thin-film technologies often used as outdoor photovoltaic solar power production. CdTe technology is most cost competitive among them. CdTe technology costs about 30% less than CIGS technology and 40% less than A-Si technology in 2011.

9.3 Cadmium telluride solar cell:

A cadmium telluride solar cell uses a cadmium telluride (CdTe) thin film, a semiconductor layer to absorb and convert sunlight into electricity. Solarbuzz has reported that the lowest quoted thin-film module price stands at US$0.84 per watt-peak, with the lowest crystalline silicon (c-Si) module at $1.06 per watt-peak.

The cadmium present in the cells would be toxic if released. However, release is impossible during normal operation of the cells and is unlikely during fires in residential roofs. A square meter of CdTe contains approximately the same amount of Cd as a single C cell Nickel-cadmium battery, in a more stable and less soluble form.

9.4 Copper indium gallium selenide:

Copper indium gallium selenide (CIGS) is a direct band gap material. It has the highest efficiency (~20%) among thin film materials (see CIGS solar cell). Traditional methods of fabrication involve vacuum processes including co-evaporation and sputtering. Recent developments at IBM and Nanosolar attempt to lower the cost by using non-vacuum solution processes.

9.5Gallium arsenide multijunction:

High-efficiency multijunction cells were originally developed for special applications such as satellites and space exploration, but at present, their use in terrestrial concentrators might be the lowest cost alternative in terms of $/kWh and $/W. These multijunction cells consist of multiple thin films produced using metalorganic vapour phase epitaxy. A triple-junction cell, for example, may consist of the semiconductors: GaAs, Ge, and $GaInP_2$. Each type of semiconductor will have a characteristic band gap energy which, loosely speaking, causes it to absorb light most efficiently at a certain color, or more precisely, to absorb electromagnetic radiation over a portion of the spectrum. Combinations of semiconductors are carefully chosen to absorb nearly all of the solar spectrum, thus generating electricity from as much of the solar energy as possible.

GaAs based multijunction devices are the most efficient solar cells to date. In October 15, 2012, triple junction metamorphic cell reached a record high of 44%.

Tandem solar cells based on monolithic, series connected, gallium indium phosphide (GaInP), gallium arsenide GaAs, and germanium Ge p–n junctions, are seeing demand rapidly rise. Between December 2006 and December 2007, the cost of 4N gallium metal rose from about $350 per kg to $680 per kg. Additionally, germanium metal prices have risen substantially to $1000–1200 per kg this year. Those materials include gallium (4N, 6N and 7N Ga), arsenic (4N, 6N and 7N) and germanium, pyrolitic boron nitride (pBN) crucibles for growing crystals, and boron oxide, these products are critical to the entire substrate manufacturing industry.

Triple-junction GaAs solar cells were also being used as the power source of the Dutch four-time World Solar Challenge winners Nuna in 2003, 2005 and 2007, and also by the Dutch solar cars Solutra (2005), Twente One (2007) and 21Revolution (2009).

The Dutch Radboud University Nijmegen set the record for thin film solar cell efficiency using a single junction GaAs to 25.8% in August 2008 using only 4 µm thick GaAs layer which can be transferred from a wafer base to glass or plastic film.

9.6 Light-absorbing dyes (DSSC):

Dye-sensitized solar cells (DSSCs) are made of low-cost materials and do not need elaborate equipment to manufacture, so they can be made in a DIY fashion, possibly allowing players to produce more of this type of solar cell than others. In bulk it should be significantly less expensive than older solid-state cell designs. DSSC's can be engineered into flexible sheets, and although its conversion efficiency is less than the best thin film cells, its price/performance ratio should be high enough to allow them to compete with fossil fuel electrical generation.

Typically a ruthenium metalorganic dye (Ru-centered) is used as a monolayer of light-absorbing material. The dye-sensitized solar cell depends on a mesoporous layer ofnanoparticulate titanium dioxide to greatly amplify the surface area (200–300 m^2/g TiO_2, as compared to approximately 10 m^2/g of flat single crystal). The photogenerated electrons from the light absorbing dye are passed on to the n-type TiO_2, and the holes are absorbed by an electrolyte on the other side of the dye. The circuit is completed by a redox couple in the electrolyte, which can be liquid or solid. This type of cell allows a more flexible use of materials, and is typically manufactured by screen printing or use of Ultrasonic Nozzles, with the potential for lower processing costs than those used for bulk solar cells. However, the dyes in these cells also suffer from degradation under heat and UV light, and the cell casing is difficult to seal due to the solvents used in assembly. In spite of the above, this is a popular emerging technology with some commercial impact forecast within this decade. The first commercial shipment of DSSC solar modules occurred in July 2009 from G24i Innovations.

9.7 Quantum Dot Solar Cells (QDSCs):

Quantum dot solar cells (QDSCs) are based on the Gratzel cell, or dye-sensitized solar cell, architecture but employ low band gap semiconductor nanoparticles, fabricated with such small crystallite sizes that they form quantum dots (such as CdS, CdSe, Sb_2S_3, PbS, etc.), instead of organic or organometallic dyes as light absorbers. Quantum dots (QDs) have attracted much interest because of their unique properties. Their size quantization allows for the band gap to be tuned by simply changing particle size. They also have high extinction coefficients, and have shown the possibility of multiple exciton generation.

In a QDSC, a mesoporous layer of titanium dioxide nanoparticles forms the backbone of the cell, much like in a DSSC. This TiO_2 layer can then be made photoactive by coating with semiconductor quantum dots using chemical bath deposition, electrophoretic deposition, or successive ionic layer adsorption and reaction. The electrical circuit is then completed through the use of a liquid or solid redox couple. During the last 3–4 years, the efficiency of QDSCs has increased rapidly with efficiencies over 5% shown for both liquid-junction and solid state cells. In an effort to decrease production costs of these devices, the PrashantKamat research group[43] recently demonstrated a solar paint made with TiO_2 and CdSe that can be applied using a one-step method to any conductive surface and have shown efficiencies over 1%.

9.8 Organic/polymer solar cells:

Organic solar cells are a relatively novel technology, yet hold the promise of a substantial price reduction (over thin-film silicon) and a faster return on investment. These cells can be processed from solution, hence the possibility of a simple roll-to-roll printing process, leading to inexpensive, large scale production.

Organic solar cells and polymer solar cells are built from thin films (typically 100 nm) of organic semiconductors including polymers, such as polyphenylenevinylene and small-molecule compounds like copper phthalocyanine (a blue or green organic pigment) and carbon fullerenes and fullerene derivatives such as PCBM. Energy conversion efficiencies achieved to date using conductive polymers are low compared to inorganic materials. However, it has improved quickly in the last few years and the highest NREL (National Renewable Energy Laboratory) certified efficiency has reached 8.3% for the Konarka Power Plastic. In addition, these cells could be beneficial for some applications where mechanical flexibility and disposability are important.

These devices differ from inorganic semiconductor solar cells in that they do not rely on the large built-in electric field of a PN junction to separate the electrons and holes created when photons are absorbed. The active region of an organic device consists of two materials, one which acts as an electron donor and the other as an acceptor. When a photon is converted into an electron hole pair, typically in the donor material, the charges tend to remain bound in the form of an exciton, and are separated when the exciton diffuses to the donor-acceptor interface. The short exciton diffusion lengths of most polymer systems tend to limit the efficiency of such devices. Nanostructured interfaces, sometimes in the form of bulk heterojunctions, can improve performance.

In 2011, researchers at the Massachusetts Institute of Technology and Michigan State University developed the first highly efficient transparent solar cells that had a power efficiency close to 2% with a transparency to the human eye greater than 65%, achieved by selectively absorbing the ultraviolet and near-infrared parts of the spectrum with small-molecule compounds. Researchers at UCLA more recently developed an analogous polymer solar cell, following the same approach, that is 70% transparent and has a 4% power conversion efficiency. The efficiency limits of both opaque and transparent organic solar cells were recently outlined. These lightweight, flexible cells can be produced in bulk at a low cost, and could be used to create power generating windows.

9.9 Silicon thin films:

Silicon thin-film cells are mainly deposited by chemical vapor deposition (typically plasma-enhanced, PE-CVD) from silane gas and hydrogen gas. Depending on the deposition parameters, this can yield:[52]

1. Amorphous silicon (a-Si or a-Si:H)
2. Protocrystalline silicon or
3. Nanocrystalline silicon (nc-Si or nc-Si:H), also called microcrystalline silicon.

It has been found that protocrystalline silicon with a low volume fraction of nanocrystalline silicon is optimal for high open circuit voltage. These types of silicon present dangling and twisted bonds, which results in deep defects (energy levels in the bandgap) as well as deformation of the valence and conduction bands (band tails). The solar cells made from these materials tend to have lower energy conversion efficiency than bulk silicon, but are also less expensive to produce. The quantum efficiency of thin film solar cells is also lower due to reduced number of collected charge carriers per incident photon.

An amorphous silicon (a-Si) solar cell is made of amorphous or microcrystalline silicon and its basic electronic structure is the p-i-n junction. a-Si is attractive as a solar cell material because it is abundant and non-toxic (unlike its CdTe counterpart) and requires a low processing temperature, enabling production of devices to occur on flexible and low-cost substrates. As the amorphous structure has a higher absorption rate of light than crystalline cells, the complete light spectrum can be absorbed with a very thin layer of photo-electrically active material. A film only 1 micron thick can absorb 90% of the usable solar energy. This reduced material requirement along with current technologies being capable of large-area deposition of a-Si, the scalability of this type of cell is high. However, because it is amorphous, it has high inherent disorder and dangling bonds, making it a bad conductor for charge carriers. These dangling bonds act as recombination centers that severely reduce the carrier lifetime and pin the Fermi energy level so that doping the material to n- or p- type is not possible. Amorphous Silicon also suffers from the Staebler-Wronski effect, which results in the efficiency of devices utilizing amorphous silicon dropping as the cell is exposed to light. The production of a-Si thin film solar cells uses glass as a substrate and deposits a very thin layer of silicon by plasma-enhanced chemical vapor deposition (PECVD). A-Si manufacturers are working towards lower costs per watt and higher conversion efficiency with continuous research and development onMultijunction solar cells for solar panels. Anwell Technologies Limited recently announced its target for multi-substrate-multi-chamber PECVD, to lower the cost to US$0.5 per watt.

Amorphous silicon has a higher bandgap (1.7 eV) than crystalline silicon (c-Si) (1.1 eV), which means it absorbs the visible part of the solar spectrum more strongly than theinfrared portion of the spectrum. As nc-Si has about the same bandgap as c-Si, the nc-Si and a-Si can advantageously be combined in thin layers, creating a layered cell called atandem cell. The top cell in a-Si absorbs the visible light and leaves the infrared part of the spectrum for the bottom cell in nc-Si.

Recently, solutions to overcome the limitations of thin-film crystalline silicon have been developed. Light trapping schemes where the weakly absorbed long wavelength light is obliquely coupled into the silicon and traverses the film several times can significantly enhance the absorption of sunlight in the thin silicon films. Minimizing the top contact coverage of the cell surface is another method for reducing optical losses; this approach simply aims at reducing the area that is covered over the cell to allow for maximum light input into the cell. Anti-reflective coatings can also be applied to create destructive interference within the cell. This can be done by modulating the Refractive index of the surface coating; if destructive interference is achieved, there will be no reflective wave and thus all light will be transmitted into the semiconductor cell. Surface texturing is another option, but may be less viable because it also increases the manufacturing price. By applying a texture to the surface of the solar cell, the reflected light can be refracted into striking the surface again, thus reducing the overall light reflected out. Light trapping as another method allows for a decrease in overall thickness of the device; the path length that the light will travel is several times the actual device thickness. This can be achieved by adding a textured backreflector to the device as well as texturing the surface. If both front and rear surfaces of the device meet this criterion, the light will be 'trapped' by not having an immediate pathway out of the device due to internal reflections. Thermal processing techniques can significantly enhance the crystal quality of the silicon and thereby lead to higher efficiencies of the final solar cells. Further advancement into geometric considerations of building devices can exploit the dimensionality of nanomaterials. Creating large, parallel nanowire arrays enables long absorption lengths along the length of the wire while still maintaining short minority carrier diffusion lengths along the radial direction. Adding nanoparticles between the nanowires will allow for conduction through the device. Because of the natural geometry of these arrays, a textured surface will naturally form which allows for even more light to be trapped. A further advantage of this geometry is that these types of devices require about 100 times less material than conventional wafer-based devices.

10. When not to do put in a Photovoltaic System:

We believe that solar photovoltaic systems can be a great energy solution for most homeowners. However, they are not the best solution for every homeowner. In talking to experienced solar contractors they estimate that about 15% of homes are not a good fit for a solar PV system. There are a number of scenarios where PV systems are impractical or where other uses of your money would get better results. In order to make a good determination you need to look at both energy generation and energy conservation.

Here is a list of scenarios where we think putting in a PV system would be ill advised:

1. **Poor Insulation** - Many homeowners have homes that are under insulated. There is no point in creating energy using solar panels only to have that very same energy go out through your roof and be wasted. Energy conservation should always come before energy generation so take care of your home's insulation first before you spend any money on a PV system. Once your home is properly insulated and if you have money left over then you can consider a PV system. Also, it is worth noting that increasingly many states will insist that your home be properly insulated before they will provide rebates for photovoltaic systems.

2. **Old Roof** - Also, if your insulation is good but your roof is on its last legs you probably should consider getting the roof done first so there is a good foundation for the solar panels. If you try to wait a few years and then do your roof then you are going to have to remove all of the solar panels first which can add unnecessary cost.

3. **Unavoidable Shade** - Solar panels are very durable devices but their performance drops significantly if all or even part of the panel is exposed to direct shade for any length of time. A competent solar contractor can analyze the location where you are thinking of putting your panels using a device called a solar Pathfinder and can tell you what the impact of shade from trees or other buildings might have. If trees are the problem you have the option to remove them. However, sometimes the trees are on a neighbors property and removing them may be more difficult. If you are in an urban area and shade is being caused by another building the problem is a good bit harder. Some states have begun enforcing the right of one homeowner not to shade out another homeowner's PV system (a right to light so to speak) so there is some chance you can take legal action to remove whatever is shading your property. However, these types of lawsuits are relatively new and it might end up being more hassle than it is worth. Consider using a pole mounted system for holding your solar panels or consider putting the panels on your garage instead of your house. If these are not options then solar PV might not be the best solution for you.

4. **The Payback is Too Long -** For some homeowners the payback period for solar energy may be too long. This is particularly true in those states that do not provide any incentives for solar energy. If you are not sure if your state provides incentives check out the database at www.dsireusa.org and you can see what incentives they offer. When all is said and done any investment should make good economic sense. Solar has its positives and negatives as an investment. On the negative side is the fact that the current administration is in the process of letting the $3000 federal solar incentive lapse. However, there is a chance this will either get overturned or brought back by the next administration. On the positive side of the equation there is the fact that both electric rates and home heating fuel costs are going up rapidly which shortens the payback period for solar. Any payback analysis should include some adjustment for the likelihood the energy rates will continue to rise. Since solar panels last a very long time (25-30 years at minimum) the question is how much will they rise. Most estimates we have seen suggest factoring in an annual rise in energy costs of 6% a year is appropriate in a payback analysis but given the recent dramatic rises in the cost of electricity in the last few years you may want to go with a higher inflation factor.

5. **Insufficient Capital -** Sometimes people just cannot afford to put in a complete PV system. A full size system can cost between $15,000 and $50,000 depending upon the size of your home and for many people these days that is just too much money to come up with. One option is to consider getting a loan for the system. A number of states have low interest rate energy loans they can provide to help support the cost of putting in a PV system. Home equity loans are also an option for those of you who still have equity in your homes given the recent decline in the housing market. While equity is down so are the interest rates on home equity loans. Also you might want to consider putting in a smaller PV system now and then adding more panels later. Once you have a basic system installed adding additional panels is relatively easy. We have seen many owners add on to their base system by looking for sales on panels when the opportunity presents itself. Finally, one option you may want to consider is going with a solar thermal system rather than a PV system. Solar thermal systems cost far less than a full-sized PV system and can still provide very significant energy savings. Most cost between $4000 to $6000 and can pay for themselves in just 3-5 years.
6. **You Are Planning to Move -** This one is just a bit tougher to judge. The question is, if you are only planning on being in your home a short time will you get a good return on an investment in a PV system. In other words will the increase in your sales price be equal to or greater than what you spent on the system. Many experts believe that adding a photovoltaic system to a home will immediately result in a significant increase in home value. However, we have heard other real estate experts tell us that given the current down real estate market the investment in a solar energy system is not completely recoverable in a short time frame. Many of the areas where this appears to be the case, such as Florida and California, are going through one of the worst housing markets in the last 50 years. If you are thinking of moving soon after installing a solar system you might want to discuss the resale value with real estate agents in your local area. House prices are a local phenomenon and what might be a good investment in solar in one area might be a bad investment in another.

11. CONCLUSION

After the extensive investigation, we found that the performance of the solar cell is not only affected by the nature of the solvent and the electrolyte, but also the particle size of the semi-conductor and the nature of the dye. When we use 0.5ml dichloromethane as the solvent with 2 drops of ethanoic acid, the maximum current achieved was 2.85mA under sunlight. Our results were 3 times better than that using the conditions recommended in the literature. Actually, conserving the world is one of the people's responsibilities and so we hope that this dye sensitized solar cell will be widely used soon so as to provide another clean and cheap energy source.

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